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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,450,542**, on November 21, 2003, by **ANATOLY AROV**, for "Arov Engine/Pump".

L. Lachance

Agent certificateur/Certifying Officer

December 20, 2004

Date

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ABSTRACT OF THE DISCLOSURE

The vane engine or pump has two or more units which are used in combination to improve the characteristics of the engine. Preferably two or more units are combined through a common drive train to maintain the units in synchronization. Each unit is of a non sliding vane design. The vanes rotate in a toroidal cylinder. A series of elliptical gears disposed in layers and connected to shafts of the vanes control the vanes. The engine can also include a vane compressor also preferably connected via the drive train to provide compressed air to the combustion chamber between vanes to provide more efficient performance of the engine. With this embodiment, the compression stroke is eliminated and the engine cycle is completed in one revolution. An efficient rotary valving arrangement is also used.

WH-12 202CA

TITLE: AROV ENGINE/PUMP

FIELD OF THE INVENTION

The present invention relates to vane engines and in particular, relates to combining vane engines or pumps, valve porting arrangements for vane engines or pumps and increasing the number of cylinders for increased capacity.

BACKGROUND OF THE INVENTION

Various designs have been proposed for vane engines which use rotatable vanes which accelerate and decelerate relative to each other to define the various strokes of a combustion engine. Examples of rotary engines are disclosed in United States Patent 3,203,405 and United States Patent 3,730,654. These prior art vane engines have relatively complicated arrangements for controlling of the vanes and have not proved entirely satisfactory.

The Arov engine/pump disclosed in my prior Canadian Patent 2,077,275 discloses a simple drive train comprising elliptical gears with an offset rotation axis which cooperate to form an elliptical drive train driving two pairs of vanes in toroidal cylinder.

One of the difficulties with my prior engine is the lack of a simple porting arrangement for supplying of the "cylinders" as well as suitable valving for compression and/or supplying a suitable air fuel mixture for combustion and valving for exhausting combustion products. With respect to a pump it is the introduction of a media to the pump during the intake stroke and the discharging of the pressurized media during the discharge stroke.

Another problem associated with vane engines is the varying torque output of the engine. It is desirable to keep the rotating mass relatively low for efficiency purposes, however, this tends to increase torque variations. Increasing the rotating mass would reduce fluctuations at the expense of engine efficiency.

The present invention overcomes a number of the above problems and also improves the operation and performance of a vane type engine by combining of the pair of cylinders and/or separating some of the functions of the four stroke cycle.

SUMMARY OF THE INVENTION

A vane engine or pump according to the present invention comprises a toroidal housing, two rotating vane assemblies rotatably mounted in the housing with the vanes cooperating with said housing to define working chambers between adjacent vanes. Each vane assembly includes a valve element which rotates with the vane assembly and selectively opens and closes passages in said housing to said working chambers for inletting and exhausting a working media. The rotary valve elements cooperate with the housing such that the position of the valve element defines media flow through said vane engine or pump.

In a preferred aspect of the invention, each vane assembly has two diagonally opposed vanes which rotate within a toroidal cylinder of said housing with said working chambers being defined between said vanes.

In a further aspect of the invention each valve element includes two outwardly extending nodes that cooperate with a cylindrical valve portion of said housing, said nodes closing ports in said housing to said

working chambers as a function of the angular position of said valve elements.

In a preferred aspect of the invention each valve element has a series of arcuate passages which correspond with ports in said housing to selectively open and close ports in said housing to said working chambers, each arcuate media passage including a port adjacent a vane of said engine or pump.

According to an aspect of the invention includes at least two combustion units interconnected by a drive train such that vane positions in respective toroidal cylinders are maintained in synchronization with each other, and wherein each unit has at least two working chambers defined by rotating vanes which accelerate towards and away form adjacent vanes as the vanes rotate in the toroidal cylinder. The vanes of each unit are driven by a corresponding gear train for controlling the vane movement as a function of the position in said cylinder and said gear trains are part of said drive train. The units cooperate with each other by being out of phase in a manner to reduce output variation.

In a preferred aspect of the invention each combustion unit has 4 working chambers.

In an aspect of the invention the engine includes a pump unit used as compressor driven by said joint drive train and providing compressed media to said working chambers of combustion units.

In a preferred aspect of the invention the engine of said drive train includes at least 6 elliptical gears synchronizing vanes position in at least two combustion units, said at least 6 elliptical gears including three gears in mesh for one pair of vanes of one combustion unit and a further three gears in mesh for a second pair

of vanes in the other combustion unit located from the opposite side of the gear train having the same vane rotation axis with the first unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are shown in the drawings, wherein:

Figure 1 is a cross section through the air of vane engine and drive train arrangement;.

Figure 2 is a vertical section through the vane engine showing each of the vanes;

Figures 3, 4, 5 and 6 respectively show the compression expansion, exhaust and suction cycles of the vane engine;

Figure 7 is a partial perspective view of the elliptical drive train of the vane engine of Figure 1;

Figure 8 is an exploded perspective view showing the various gears and drive trains used in the vane engine of Figure 1;

Figure 9 is a sectional view through two combustion units interconnected by a common drive train;

Figure 10 is a sectional view through the vane engine showing the common gear train;

Figures 11 through 14 show the relationship of the two of Figure 9 and the complementary positions of the vanes in the two toroidal cylinders;

Figure 15 is a partial sectional view through eight vane engine units interconnected by a particular drive train;

Figure 16 is a top view of the combination of Figure 15 showing the gears of the drive train;

Figure 17 is a top view of an engine combination having three combustion units;

Figure 18 is a sectional view through the engine of Figure 17;

Figure 19 is a vertical section view through a vane engine unit showing a particular valving arrangement for introducing a working media during the intake stroke and exhausting any products in the exhaust stroke;

Figure 20 is a top view showing the valve porting of Figure 19;

Figure 21 is a sectional view through the vane engine unit having a different valving arrangement;

Figure 22 is a top view of the engine unit of Figure 21 showing the valving;

Figure 23 is an exploded perspective view of a vane engine unit showing a particular valving arrangement; and

Figure 24 shows the rotating valve element connected to a pair of rotary vanes;

Figure 25 is an exploded perspective view of an alternate version of the vane engine having stationary valve element with arcuate valve ports;

Figure 26 is a schematic cross sectional view of the vane engine of Figure 25;

Figure 27 is a cross sectional view of the stationary valve element;

Figure 28 shows the engine at different angular positions and the cycles thereof when compressed media air and fuel is provided to the engine unit at the appropriate times; and

Figure 29 is a schematic view similar to Figure 28 showing the operation of the Arov engine for a four stroke operation where a complete cycle takes two revolutions or 720 degrees.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The vane engine 2, as shown in Figures 1 and 2, has a combustion unit with a toroidal cylinder and vane arrangement 4, in combination with a drive train arrangement for controlling of the vanes, generally shown as 6. The vanes of the engine are shown as 11 and 11^1

being diagonally opposite vanes and commonly attached, and associated vanes 12 and 12^1 also being diagonally opposed and commonly connected. The pairs of vanes 11 and 11^1 and 12 and 12^1 also being diagonally opposed and commonly connected. The pairs of vanes 11 and 11^1 and 12 and 12^1 are separately associated with one of the inner coaxial shaft 20 and the outer coaxial shaft 22. Thus, one set of vanes is driven by one shaft and other pair of vanes is driven by the other shaft. The engine also includes an exhaust port 16 and intake port 14 associated with the movement of the vanes and fixed relative to the rotary cylinder defined by the inner cylinder wall 30 and the outer cylinder wall 32.

The cycle of the vane engine is shown in Figures 3 through 6. In Figure 3, vanes 11 and 12^1 are shown in the final stages of compression or exhaust states. In Figure 4, the vanes have been moved to an intermediate position of expansion state, such as would be common if this is a suction or combustion after engine spark was introduced with completion of the compression cycle shown in Figure 3. In this case, vane 12^1 is accelerating away from vane 11^1 and, thus, creates the combustion or suction stage. In Figure 5, the vanes have moved to the end of combustion or suction stage or the start of compression or exhaust stage. In Figure 6 the vanes have been moved to an intermediate position of compression or exhaust state and vane 12^1 is accelerating towards vane 11^1 and defines the compression or exhaust of the spent products of combustion.

Figure 7 shows the elliptical gears interconnected to form two separate drive trains where the gears on the left are driven by a common shaft and the gears on the right are each driving one of the two coaxial shafts 20 and 22. This can be further understood with respect to a review of the exploded perspective view of Figure 9. In this case, a common shaft 18 drives the two elliptical

gears 40cl and 40cw, with each of these gears being keyed to the shaft. In the preferred embodiment for driving of a vane engine, these gears are identical and are keyed to the shaft 180° out of phase. The degree of out of phase will depend upon the desired relationship of the movement resulting when the common shaft 18 is rotated and causes sympathetic movements of shafts 20 and 22. Any degree of out of phase is possible. Two separate drive trains are defined by a first pair of elliptical gears 40cl and elliptical gear 41 with a second drive train being defined between elliptical gear 40c2 and elliptical gear 43. Elliptical gear 41 is attached to the outer coaxial shaft 22 and elliptical gear 43 is keyed to the inner coaxial shaft 20.

Each gear train or each securement of an elliptical gear to the respective shaft is positioned such that the elliptical gear rotates about one of its foci. The focus of each elliptical gear is shown as 44, whereas the geometric center of the gear is shown as 42. As shown in Figure 8, the gears are positioned such that the foci are all aligned. This will occur at this position of the gears as well as when the gears have rotated 180°. With the gears in this position, it can be seen that the focus of one of the two gears is located between the common shaft 18 and the respective coaxial shaft 20 or 22, and the remaining focus is located beyond the shafts. It can also be seen that elliptical gear 40cl and elliptical gear 40c2 is 180° out of phase, and therefore, elliptical gears 41 and 43 will also be 180° out of phase. With this arrangement, four elliptical gears have been used to control the motion of the vanes and impart the desired degree of acceleration and deceleration. The use of the ellipse as a starting point for the drive train is desirable, in that each gear can be identical. The use of this shape also simplifies manufacture of the gears.

The exact characteristics of the ellipse can be varied to adjust the desired acceleration and deceleration of the vanes and also maximum vanes opening angle for a particular engine or pump. Although the present drive train has been described with respect to a vane engine 2, this vane engine, in fact, could be a vane pump corresponding to a toroidal piston type pump. In this case, the power would be inputted through the common shaft 18. In the case of an engine, the power output from the engine would be taken out common shaft 18, and because of the offsetting nature of the gears in the Arov engine, the power available to the common shaft would have fairly good leverage. This leverage is high as the forces of combustion act directly on, and are generally perpendicular to the vanes to cause rotary motion without conversion from linear to rotational movement as found in piston type engines. In addition, the gear train also increases the torque and horsepower characteristics due to the multiplier effect of the gear ratio. These characteristics change with angular position, however, twinning of combustion units smoothes the variations. It can also be appreciated that if vibration is a problem, appropriate counterweighting or modifying of the gears to provide a more efficient weight balancing can be used. Typically, counterweighting is not required for multiple unit operation.

Figures 9 through 14 show different details of the Arov twin engine 100. In this case, the first combustion unit 102 is connected via the gear train 106 to a similar or second combustion unit 104. With reference to the blades generally shown in Figure 9, the first and second combustion units are <u>90 degrees out of phase</u>.

Twinning of the vane combustion units via the connecting gear train 106 considerably reduces the variations in the output torque. The connecting gear train 106 includes a first gear train comprising gears

110, 112 and 114 where vane 122 of combustion unit 102 is linked to the movement of vane 126 in toroidal cylinder of combustion unit 104. A second set of gears 116, 118 and 120 are used to control the position of vane 124 of combustion unit 102 toroidal cylinder and vane 128 in toroidal cylinder of combustion unit 104. As can be appreciated there are opposite vanes in each engine which are not discussed. These vanes are paired with a vane of the opposite engine.

The output from the engine is transmitted through shaft 130. It can be appreciated that if this is a pump arrangement, then the outward shaft 130 would be an input shaft 130. As can be appreciated from a review of Figures 11 through 14, a first gear train of three gears and a second gear train of three gears control and coordinate the movement of the vanes in a first toroidal cylinder of combustion unit 104 and in a second toroidal cylinder of combustion unit 104 in a particular manner. With this arrangement, the torque output of the twin engine has considerably less variation. If the arrangement is used as a pumping arrangement, the output of the pumps can be combined and less variation in the motor torque occurs. Preferably, the gear train arrangement includes three pairs of elliptical gears where a middle set of elliptical gears acts to tie the two combustion units together. Each of the gears is preferably an elliptical gear with an offset shaft drive position. In a preferred embodiment, all gears are the same. In the pump application it is possible to use the unit to extract power from a pressurized gas. In this case, the pressurized gas media powers the unit, which is driving an electrical generator or other device. The pressurized gas will reduce in pressure. This is useful reducing pressure in natural gas and using the energy to generate electricity.

The general concept of combining several combustion units via an intermediate pair of gears is further expanded in Figure 16. This Figure shows a common central pair of gears with four combustion units positioned exterior thereto and in mesh with the central gears. From a review of Figure 16, it can be seen the combination of four combustion units using the particular gear train.

The concept generally shown in Figure 16 is again expanded in the embodiment of Figure 15. In this case, the multiple Arov engine 140 has eight combustion units tied together. Four of these units are using a first and a second row of Gears in the gear train 142. The connecting gear train 142 has three levels of elliptical gear trains. Basically, the connecting gear train for eight units can share one set of connecting gears thereby reducing the number of gears and the number of layers of gears. Stacking of the Arov engines requires two hollow shafts for each pair of engines and a common shaft for each pair of engines. The common shaft is connected to the middle gear in the stack of gears.

A further variation of the multiple Arov engine is shown in Figure 17. In some cases, it is desirable to use a triple Arov engine as shown in Figure 17. Each of the individual units is coordinated with the other and the output torque has considerably less variation.

A further variation of the structure of Figure 17 is using one of the units 150 as a compressor for feeding compressed air and/or air and fuel to the combustion units 152 and 154. This provides advantages by eliminating compression and suction steps for both engine cylinders. The compression unit 150 need not operate at the identical speed to the rotary vane engines and preferably operates at higher multiple speeds.

One of the issues associated with a rotary vane engine or multiple rotary vane engines as disclosed in the present application, is providing a simple valving arrangement for the intake and exhaust corresponding with the space between the leading and trailing rotary vanes. A number of different valving arrangements are possible which use a rotary valve element associated with the vanes as will be described with respect to Figures 19 through 24.

As shown in Figure 23, each set of rotary vanes 160 has associated therewith a rotary valve element 162. This rotary valve element includes two outwardly extending lobes 164 and 166 which are separated from each other by connecting gaps 168 and 170. Basically, the outwardly extending lobes 164 and 166 close the intake or exhaust ports associated with the housing 180. The connecting passage 185 connects the inlet 168 to a discharge location 191 associated with the vane 193. A similar passage 187 connects inlet 168 with the discharge port 195 associated with the vane 197. In this way, the rotary valve element 162 allows connection of a port with a desired position associated with the particular vanes 193 and 197. At the bottom of Figure 23, a similar arrangement is associated with the further vanes 199 and 201. An intake port 203 is shown at the base of Figure 23 and is presently closed by the lobe 163. It can be seen how the ports in the rotary valve element also connect with the desired discharge positions 205 and 207 at desired points relative to the vanes 201 and 199. An exhaust in the housing port 211 is shown near the top of the engine of Figure 23.

The ports 191, 195, 205 and 207, and the passages 185, 187, 210 and 213 form both inlet passages and exhaust passages for the working chambers defined between the vanes. With this arrangement, four working chambers

supply and release of media are defined by the two rotary valves.

With this arrangement, the particular ports associated with the housing of the engine are connected to the rotary vanes to discharge at a desired location at a particular point relative to the vane. This provides an efficient valving arrangement for intake and exhaust strokes or supply and pressure strokes associated with an engine or pump. The individual parts can be easily pinned or joined together for proper synchronization.

In the embodiments of Figures of 21 and 22, two rotary valve elements are used. It is possible to use a different rotary valve element as generally shown in Figures 19, 20 and 24. In this case, a series of channels at different positions are provided and are connected with the corresponding vanes for the desired positioning. This is necessary for a four stroke design. In some cases, the rotary engine will only define the two working chambers and the other chambers will not effectively be used.

Thus alternate valving arrangement is schematically shown in the exploded perspective view of Figure 25. In this case for clarity, the left and right stationary valve elements have been rotated 90 degrees such that the various channels are visible. In practice, these would be turned to face the circular plate member of the vane followers for operation with the ports in the circular member.

The engine assembly 200 as shown in Figure 25 has a left vane assembly 202, a right vane assembly 204, a left stationary valve element 206, and a right stationary valve element 208. The left vane assembly shows the following vanes where the right vane assembly shows the leading vanes. The left vane assembly includes a

circular vane holder 205 which rotates with the vanes and includes therein port 214 and port 218. Port 214 as illustrated in Figure 26 is located adjacent an exterior portion of the vane and port 218 is positioned at a reduced radial spacing. Port 214 cooperates with feed track 226 and the exhaust track 224 whereas port 218 cooperates with feed track 228 and exhaust track 230.

With the right vane assembly and the right stationary valve element, port 216 cooperates with feed track 234 and exhaust track 236 and port 220 cooperates with feed track 238 and exhaust track 240. Each of the ports 214, 216, 218 and 220 are positioned to slide over their respective tracks and form either an inlet or an exhaust function. Once these ports move to a position where they are not connected to the tracks, this is a closed valve condition. In addition, it is possible to have each of the suction or exhaust inlets or outlets 250, 252, 254, 256, 260, 262, 264 and 266, have their own valve which can be opened or closed. This is of assistance where the four stage cycle is completed in 720 degrees of rotation.

With the rotary engine of Figure 25, there are effectively four inlets and four exhaust outlets. Each of the vane assemblies include their own stationary valve element having the various tracks therein for connecting with ports associated with each of the vanes where these ports are used for both inlet and exhaust purposes.

The sectional view through the stationary valve shown in Figure 27 shows the feed track 234 connected to the feed inlet 260 as well as the feed track 238 connected to the feed inlet 262.

Figure 28 is a schematic showing a twin engine configuration where each of the combustion units is being fed a compressed mixture of air and fuel for combustion.

The first upper unit shows four working chambers, namely two chambers A and two chambers B. The valving for appropriately providing compressed air through inlet 310 and exhausting from many of the working chambers through outlet 312 would preferably use the two rotary valve elements shown in Figure 23. Chamber A with its charge of compressed air and fuel is about to pass ignition points 11 and 13 which will occur at approximately 45 degrees as shown in the chart of Figure 28. The leading vane 322, 324 will then quickly accelerate from the trailing vane 321, 323. Combustion and expansion continues to approximately 180 degrees of shaft 130 rotation. This will have caused an exhaust stroke after combustion in chamber B which will then receive a compressed air and fuel charge and undergo its own combustion cycle. Four ignition sources, I1, I2, I3 and I4 are shown.

The second lower unit which is linked by a gear train as shown in the earlier Figures, is shown below upper unit A and is out of phase by 90 degrees. Similar structures shown and the combustion cycle is 90 degrees apart with this arrangement a smoothing of a torque output is achieved. As seen from the timing diagram associated with the chambers A, B, C and D, the combustion portions of the chambers overlap such that relative to the combined engine, there is always a combustion stroke at all times. The power of the combustion stroke will change somewhat, however, as the combustion stroke of one chamber starts to decrease, the combustion stroke in the other is starting to increase. In this way, the torque output is very smooth.

Figure 29 shows an overall schematic of the four stroke operation of the Arov engine. In this case, each of the four inlets shown can be selectively closed using suitable valving as previously described. With this structure, the four step cycle for each combustion

chamber is carried out over 720 degrees, four different ignition sources I1, I2, I3 and I4 are shown. With respect to combustion chamber A, for the first 180 degrees shaft 130 rotation, a chamber is expanding to draw air into the chamber, between 180 and 360 degrees the chamber is reduced in size to form the compression stroke. Fuel is appropriately added either during the suction stage or during the compression stroke. At about 360 degrees, I1 fires, causing combustion and expansion of chamber A for the next 180 degrees. The following 180 degrees forms the exhaust stroke. The chart of Figure 29 shows the various stages for each of the chambers relative to chamber A.

The combining of several combustion units using the gear train provides a simple means for reducing output variations. It is also possible to combine two engine units with a third compressor unit which is also in the form of a vane pump to supply a compressed air charge to the engines and thus avoid the compression stroke of the engine. In addition, this compressor can also be used to assist in the exhaust of combustion products by effectively providing a vacuum source. The additional compressor can also be used merely to improve the compression cycle if this is so desired by providing precompression of the charge. With this arrangement, the four working chambers of the engine can go through the four step engine cycle in 360 degree rotation as opposed to 720 degrees if a separate compressor is not used.

With the present invention, it is possible position combustion units planetary to shaft 130 and to use a planetary gear train around shaft 130 stack the number of combustion units to either side of the gear train and use a common drive train to effectively control the position of all vanes. This also assists in effectively transferring the power to the opposite engine as required for the particular cycle. In the case of a

pump operation of the system, the output gear is effectively the drive gear for the overall combination. With the present invention, it is economical to expand the output requirements merely by combining combustion units using the planetary gear train and stacking elements. This provides cost advantages as the same engine elements are effectively used and merely more engine units are provided and combined to improve the output when more power is required. Thus for a particular application, the appropriate number of engines can be combined and if the demand changes in the future, additional units can often be added. Furthermore, it can be appreciated that efficiencies are also achieved in the manufacture of the engines in that the precise output requirements can be met by combining of the units as opposed to warehousing a whole series of engines having different output characteristics.

The present invention also discloses a unique valving arrangement to improve the supply and exhaust of working media to/from the working chambers.

Although various preferred embodiments of the present invention have been described herein in detail, it will be appreciated by those skilled in the art, that variations may be made thereto without departing from the spirit of the invention or the scope of the appended claims.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A vane engine or pump comprising a toroidal housing, two rotating vane assemblies rotatably mounted in said housing with said vane assemblies cooperating with said housing to define working chambers between adjacent vanes, each vane assembly including a valve element which rotates with the vane assembly and selectively opens and closes passages in said housing to said working chambers for inletting and exhausting a working media; said rotary valve elements cooperating with said housing such that the position of said valve element defines media flow through said vane engine or pump.

2. A vane engine as claimed in claim 1 wherein each vane assembly has two diagonally opposed vanes which rotate within a toroidal cylinder of said housing with said working chambers being defined between said vanes.

3. A vane engine as claimed in claim 1 or 2 wherein each valve element includes two outwardly extending nodes that cooperate with a valve portion of said housing, said nodes closing ports in said housing to said working chambers as a function of the angular position of said valve elements.

4. A vane engine or pump as claimed in claim 1 or 2 wherein each valve element has a series of arcuate passages which correspond with ports in said housing to selectively open and close ports in said housing to said working chambers, each arcuate media passage including a port adjacent a vane of said engine or pump.

5. An engine or pump assembly comprising at least two combustion units interconnected by a drive train; each combustion unit having a toroidal cylinder with a pair of

rotating vane assemblies; each vane assembly including two vanes with vanes of one assembly cooperating with vanes of the other vane assembly to define at least two working chambers which change in volume as the vanes rotate in said toroidal cylinder; said vane assemblies of each combustion unit being driven by a corresponding gear train for controlling the vane movement as a function of the position in said toroidal cylinder with said gear trains of said combustion units being interconnected to form said drive train; said drive train controlling the relative position of the vane assemblies of both combustion units and thereby determine the relative position of said vanes and wherein said units cooperate by being out of phase with each other in a manner to reduce output variation.

6. An engine or pump assembly as claimed in claim 5 wherein each combustion unit has 4 working chambers.

7. An engine or pump assembly as claimed in claim 5 or 6 used as an engine and including a compressor unit driven by said joint drive train and providing compressed media to said working chambers of said combustion units.

8. An engine or pump assembly as claimed in claim 7 wherein said drive train includes at least 6 elliptical gears synchronizing vane positions in two combustion units, said at least 6 elliptical gears including 3 gears in mesh for one pair of vanes of one unit and one pair of vanes of the other unit, and a further 3 gears in mesh for a second pair of vanes in the one unit and a second pair of vanes of the other unit.

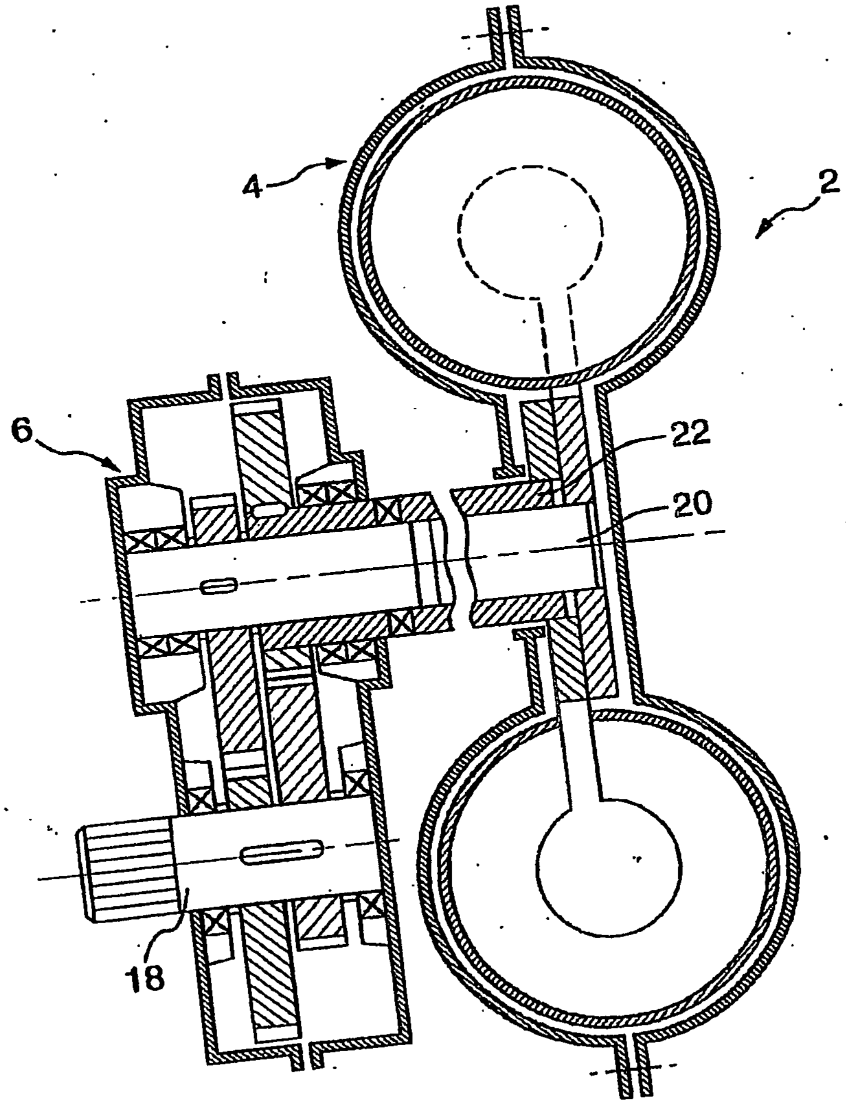

FIG.1 (prior art)

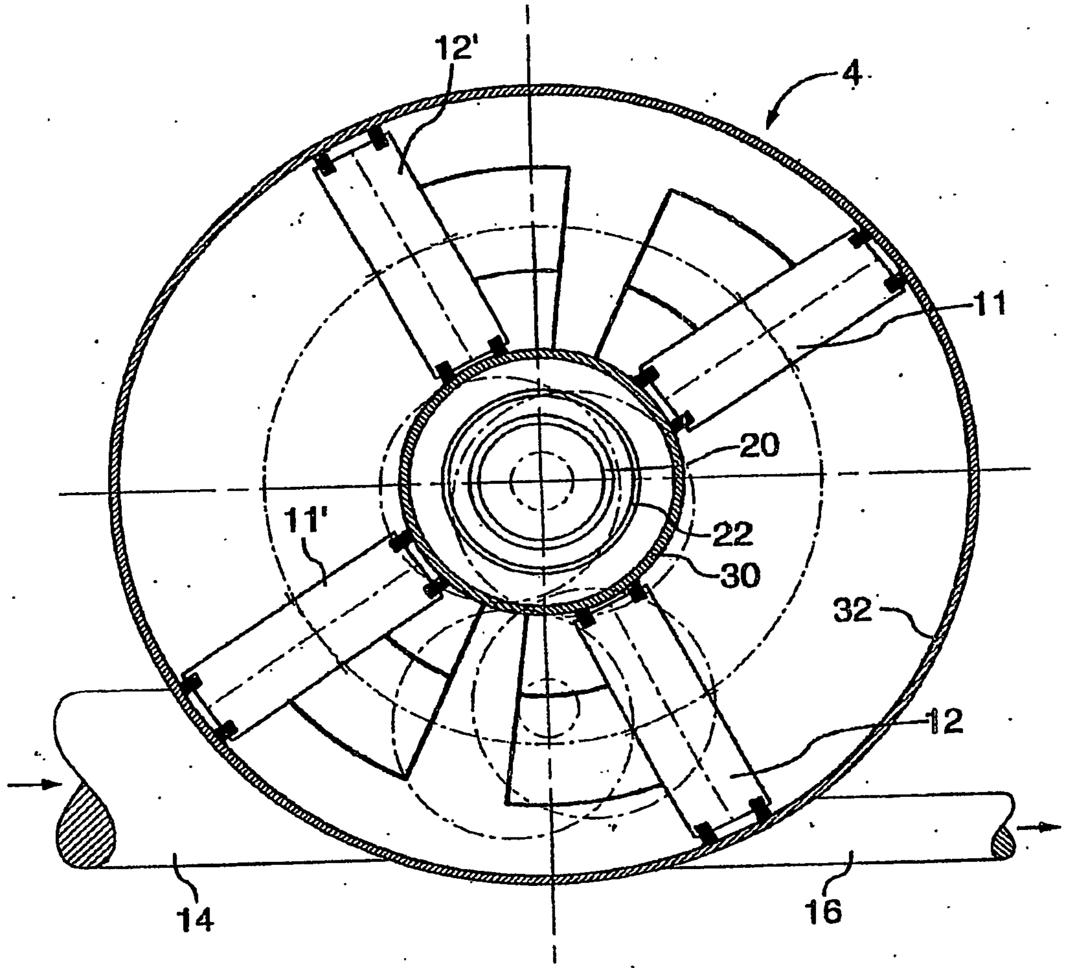

FIG.2 (prior art)

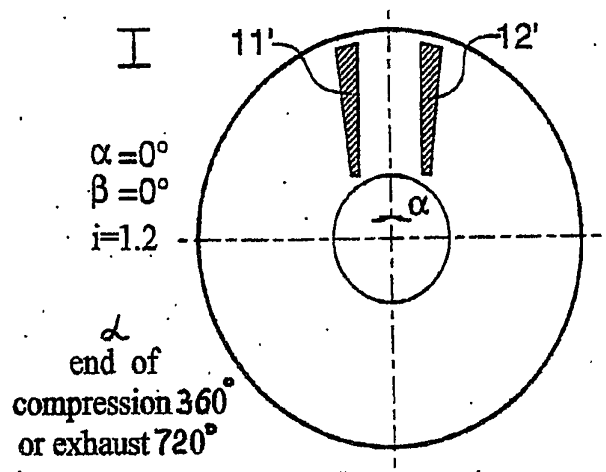

FIG.3 (prior art)

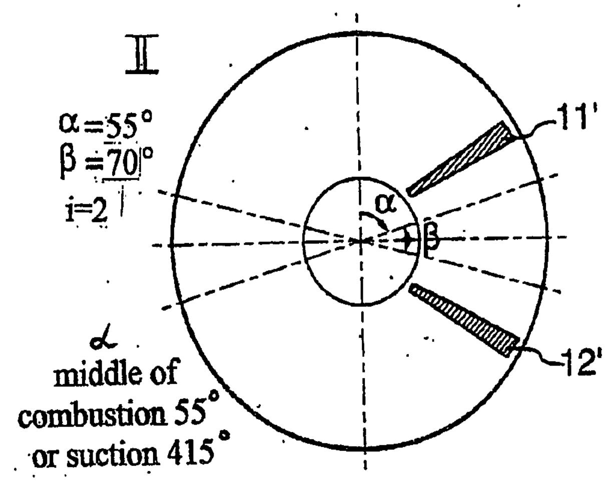

FIG.4 (prior art)

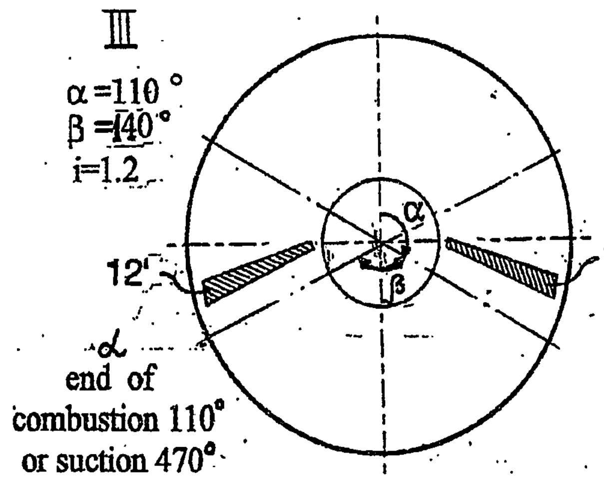

FIG.5 (prior art)

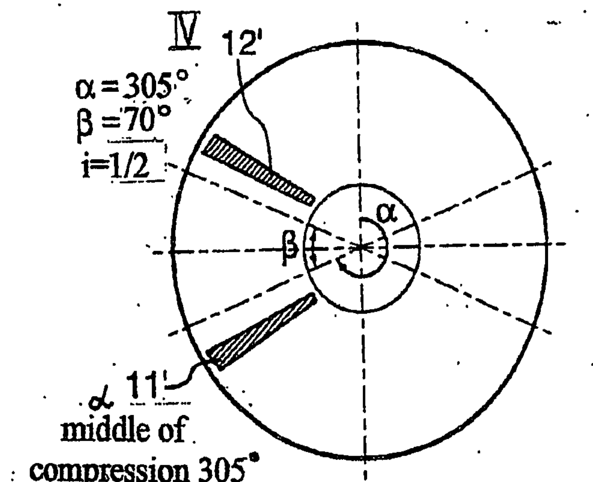

FIG.6 (prior art)

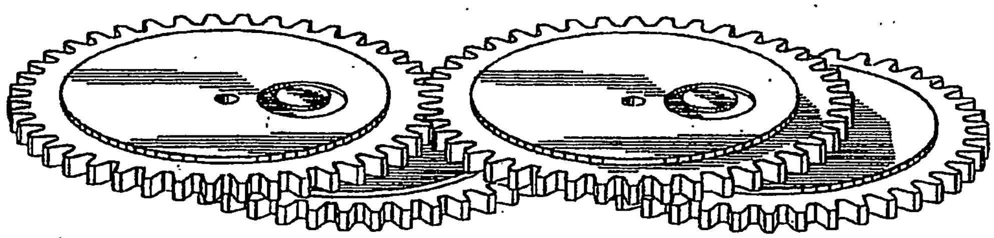

FIG.7 (prior art)

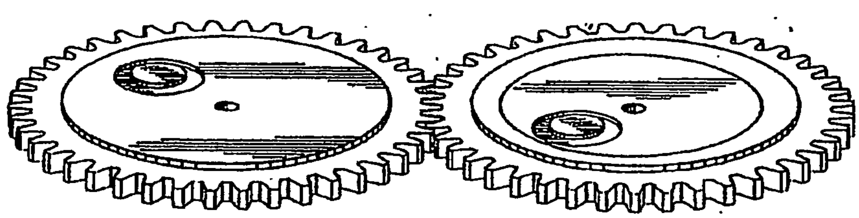

FIG.8 (prior art)

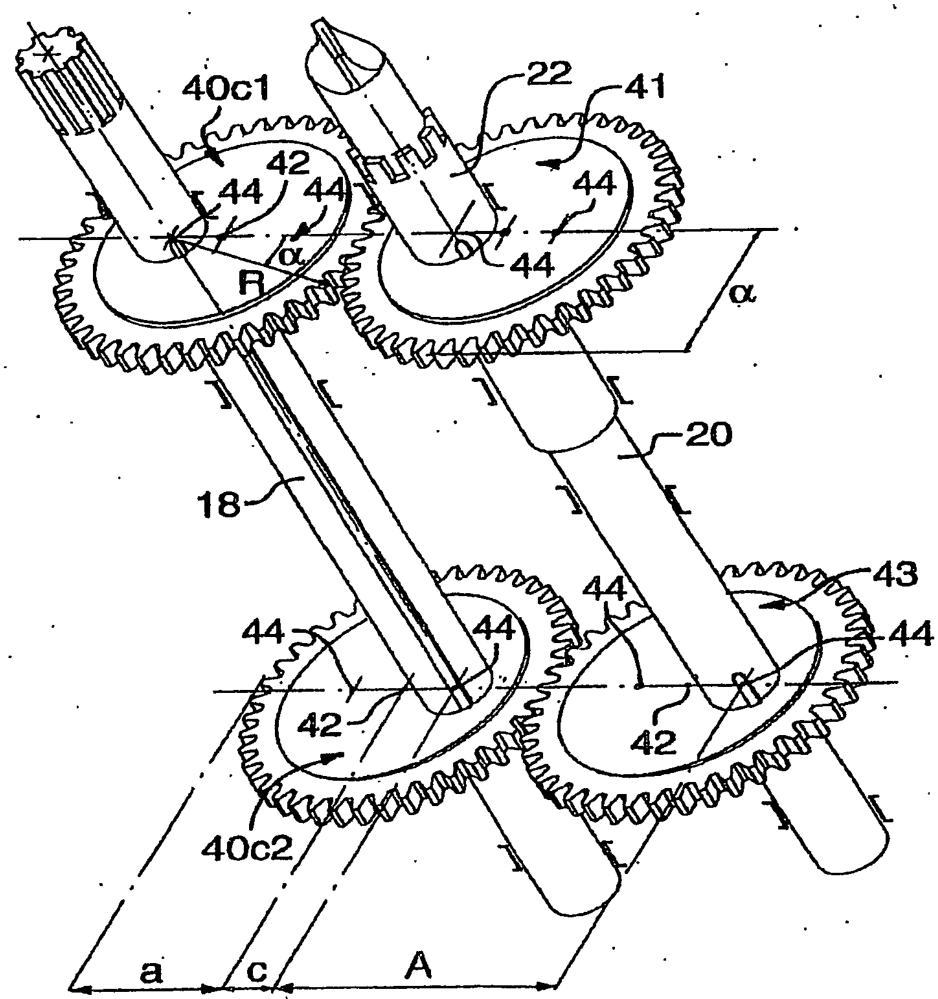

FIG.9 (prior art)

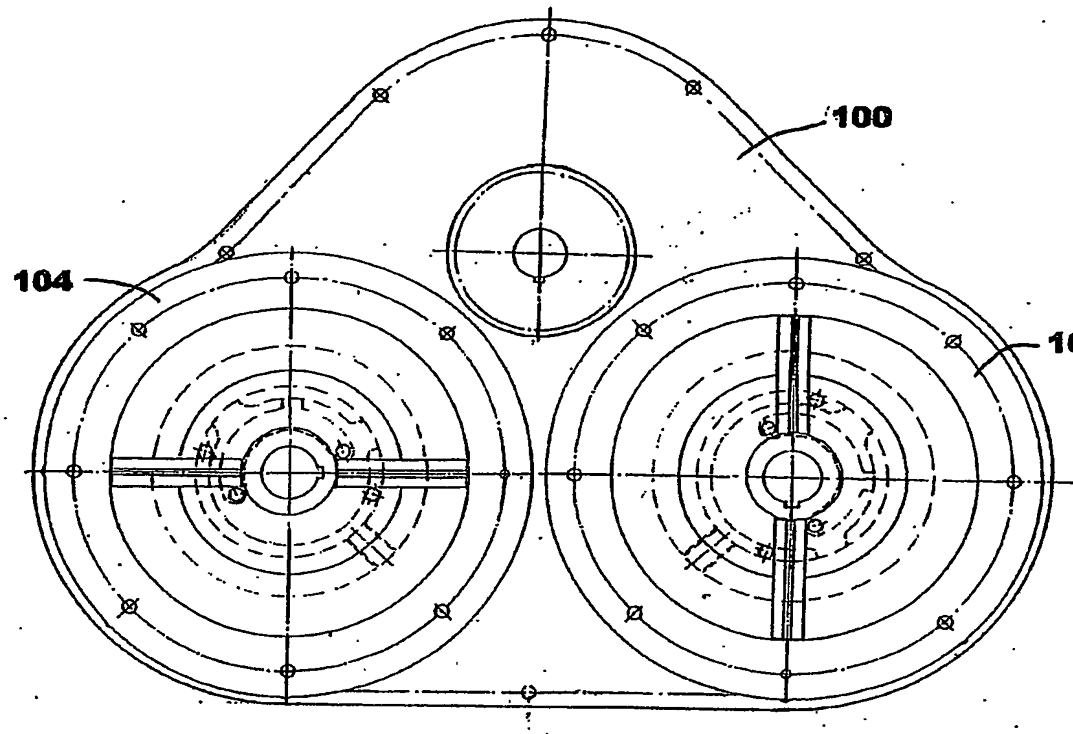

Fig. 9

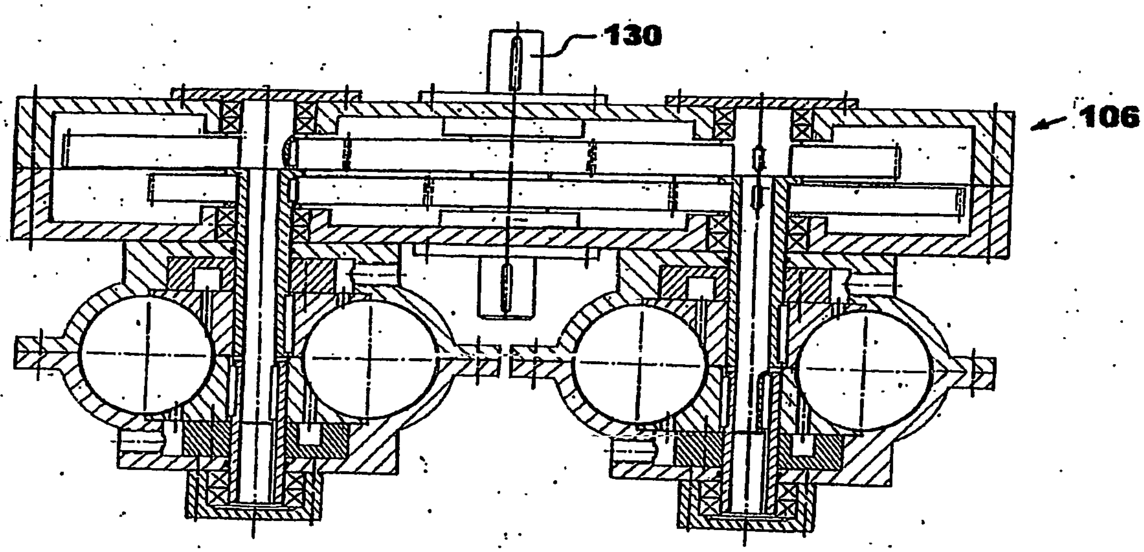

Fig. 10

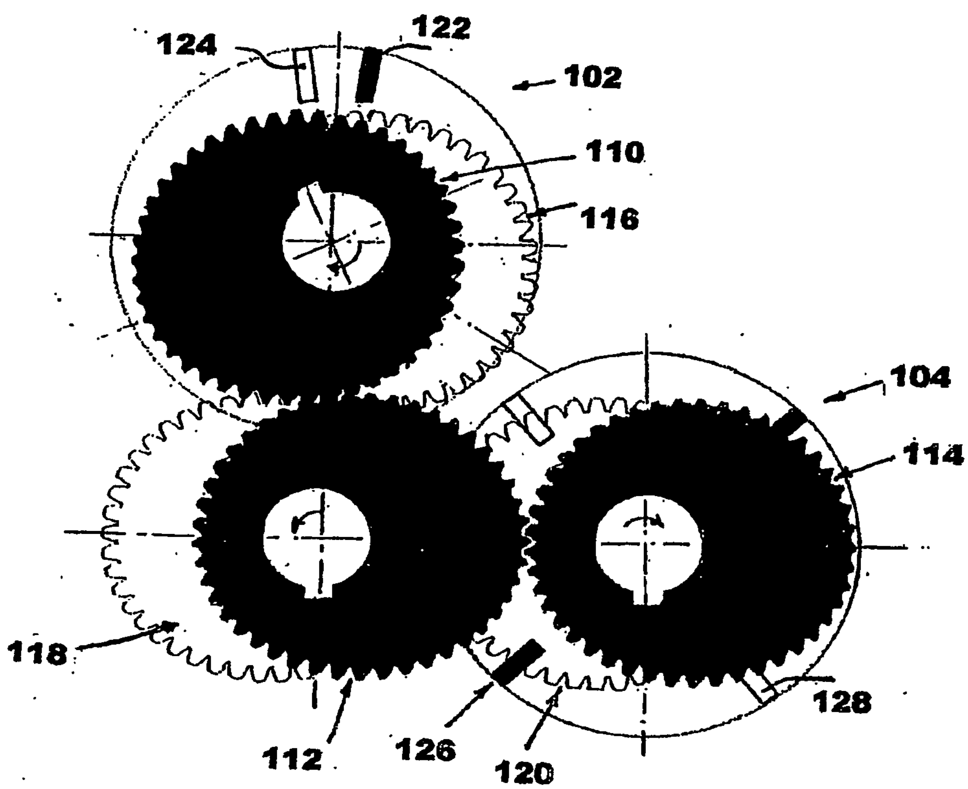
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Fig. 11

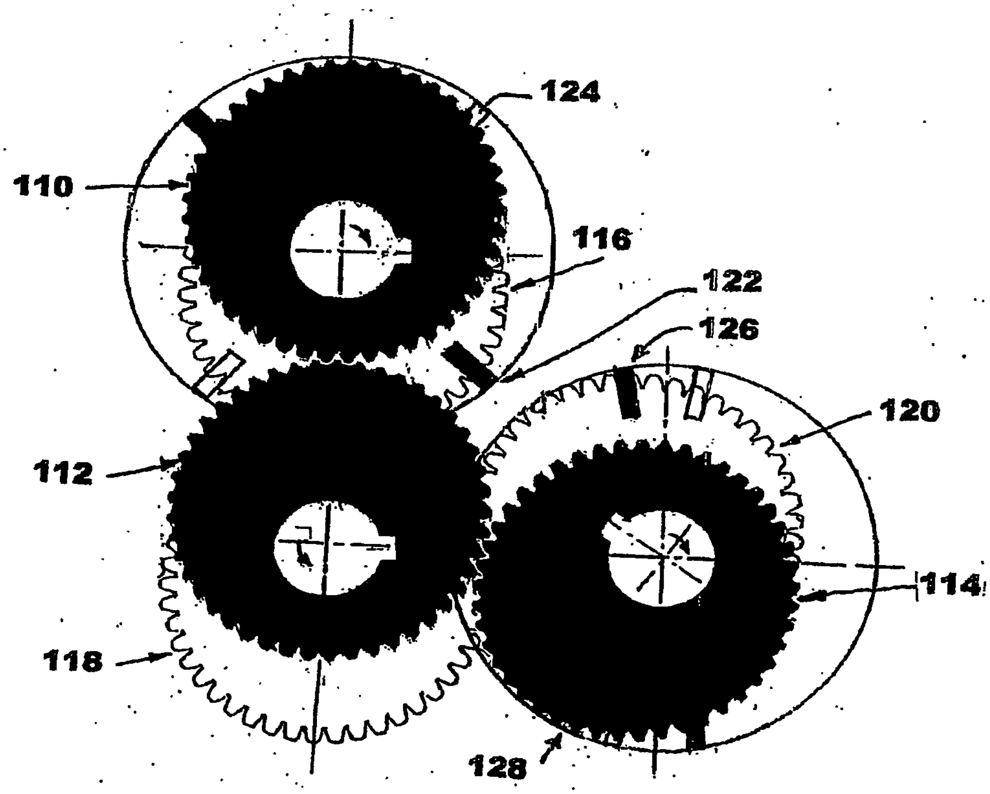
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Fig. 12

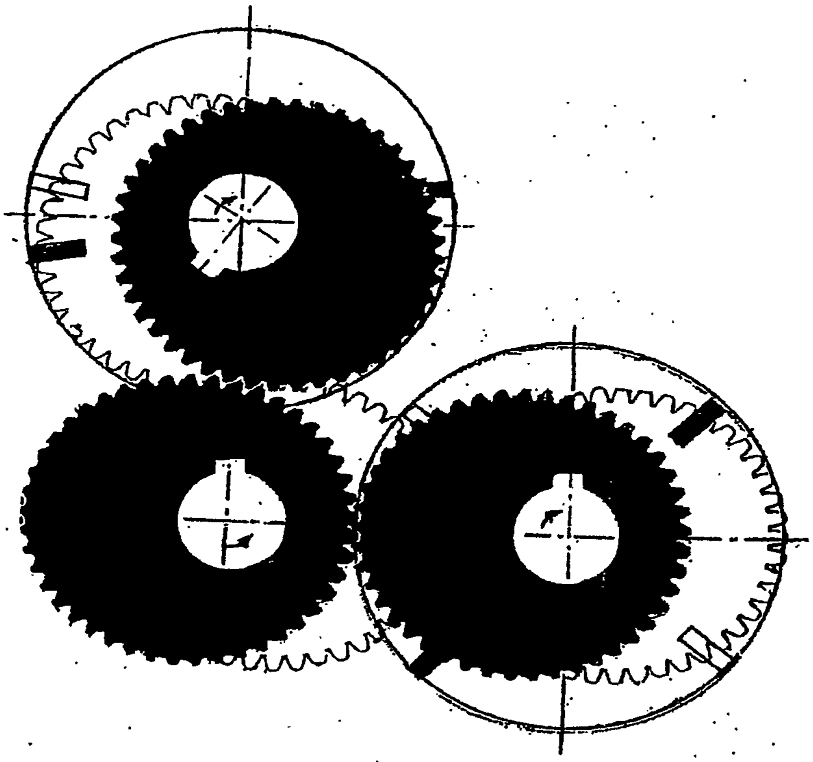


Fig. 13

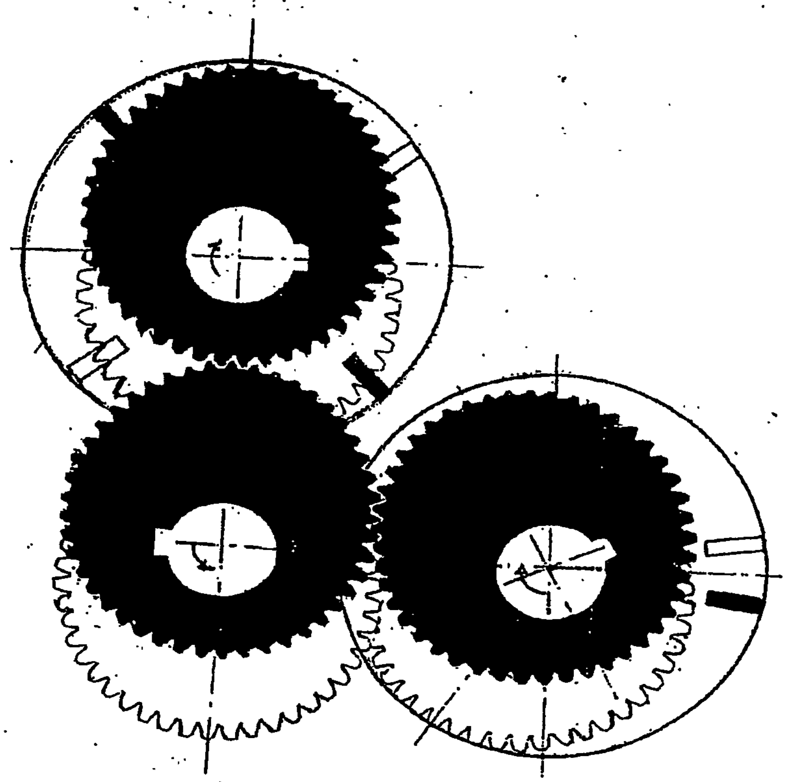


Fig. 14

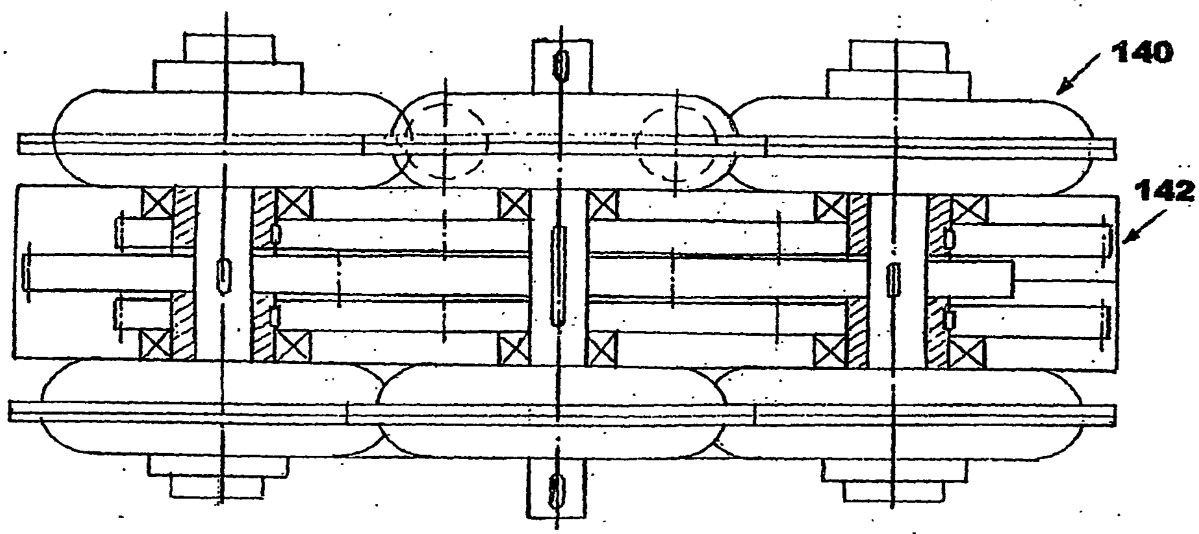


Fig. 15

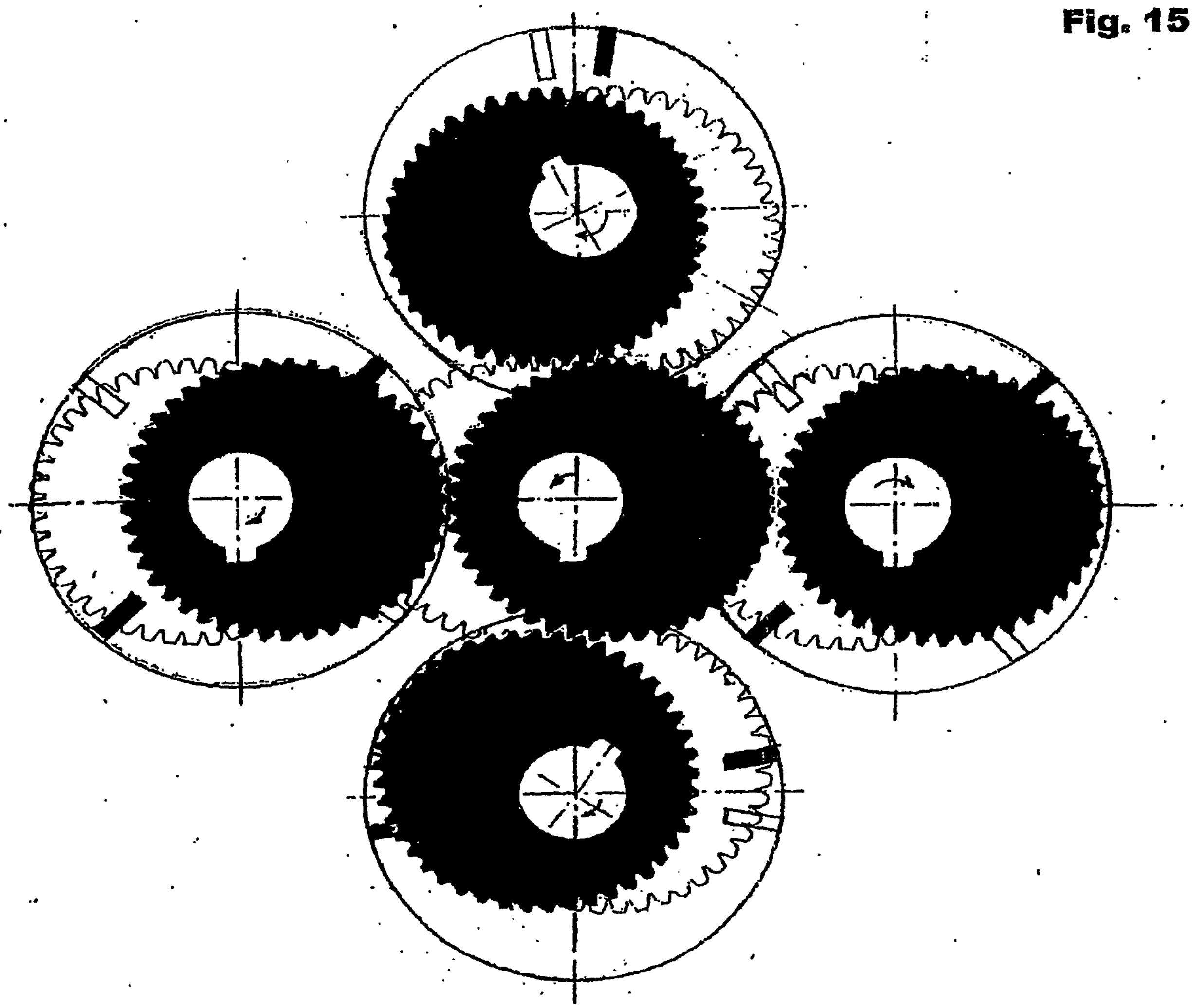


Fig. 16

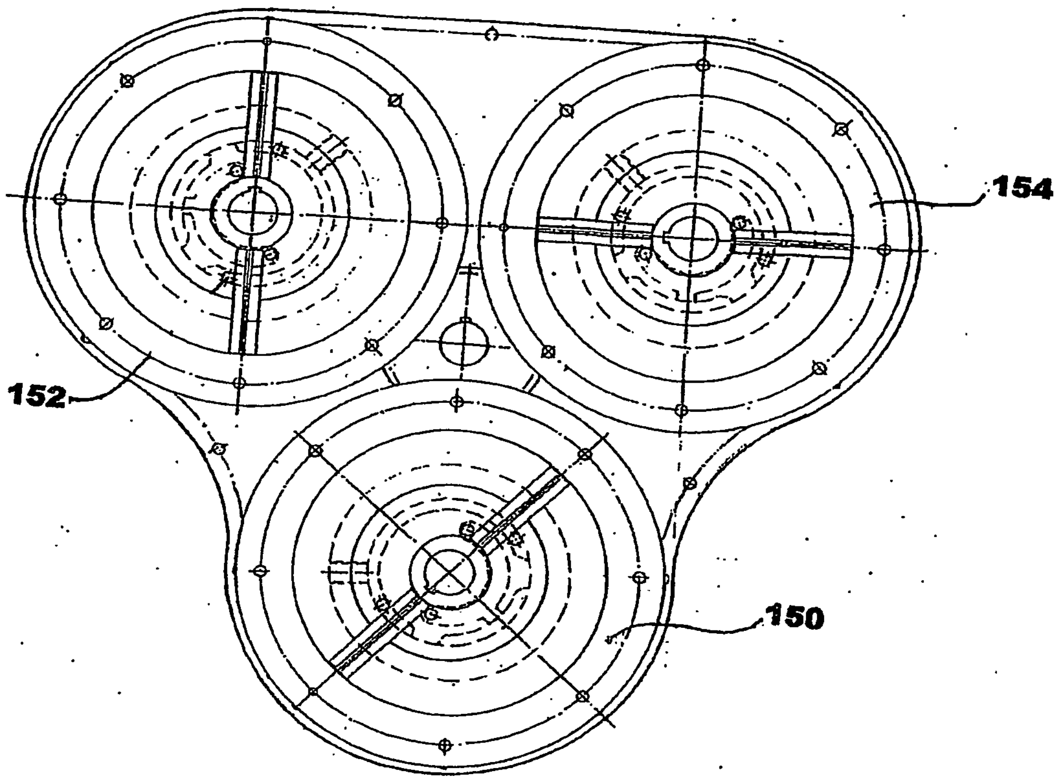


Fig. 17

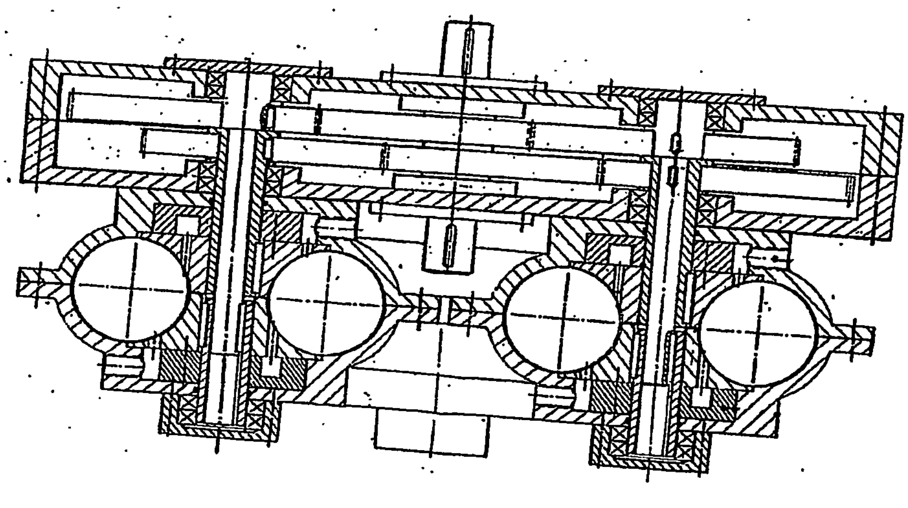


Fig. 18

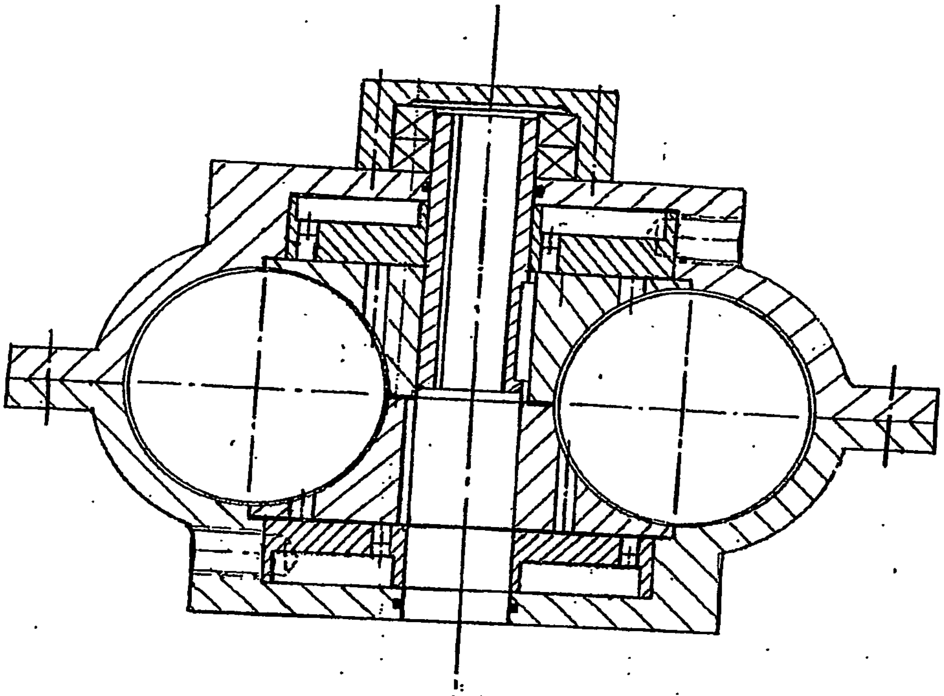


Fig. 19

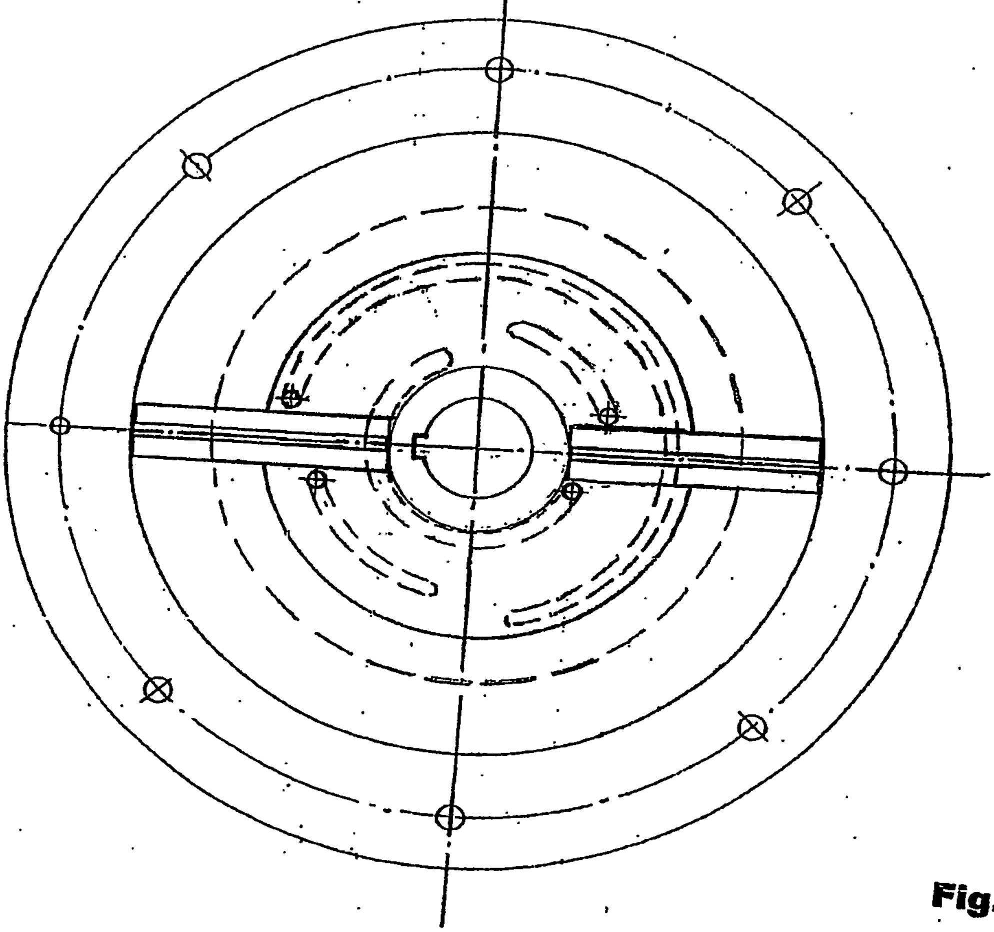


Fig. 20

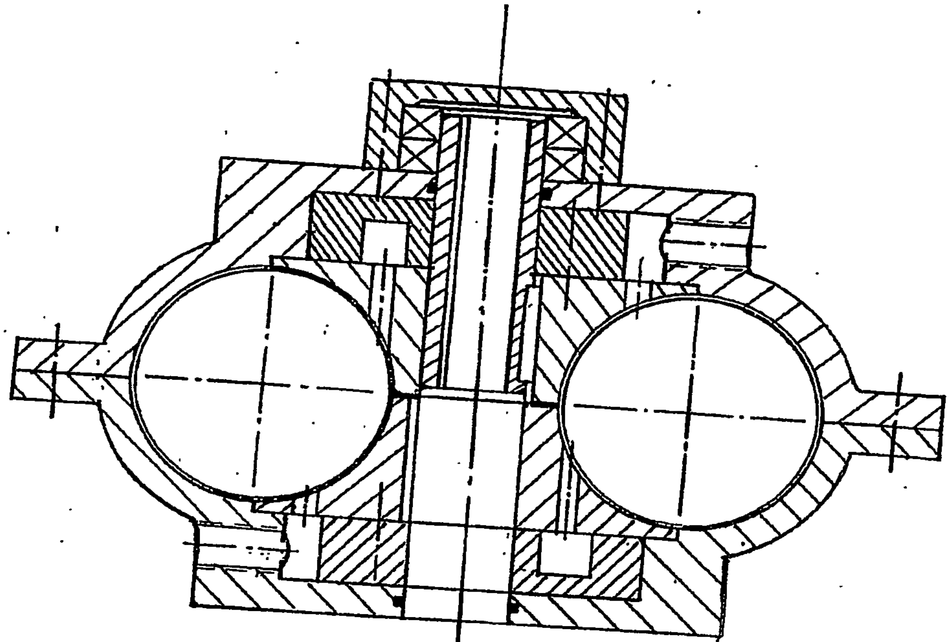


Fig. 21

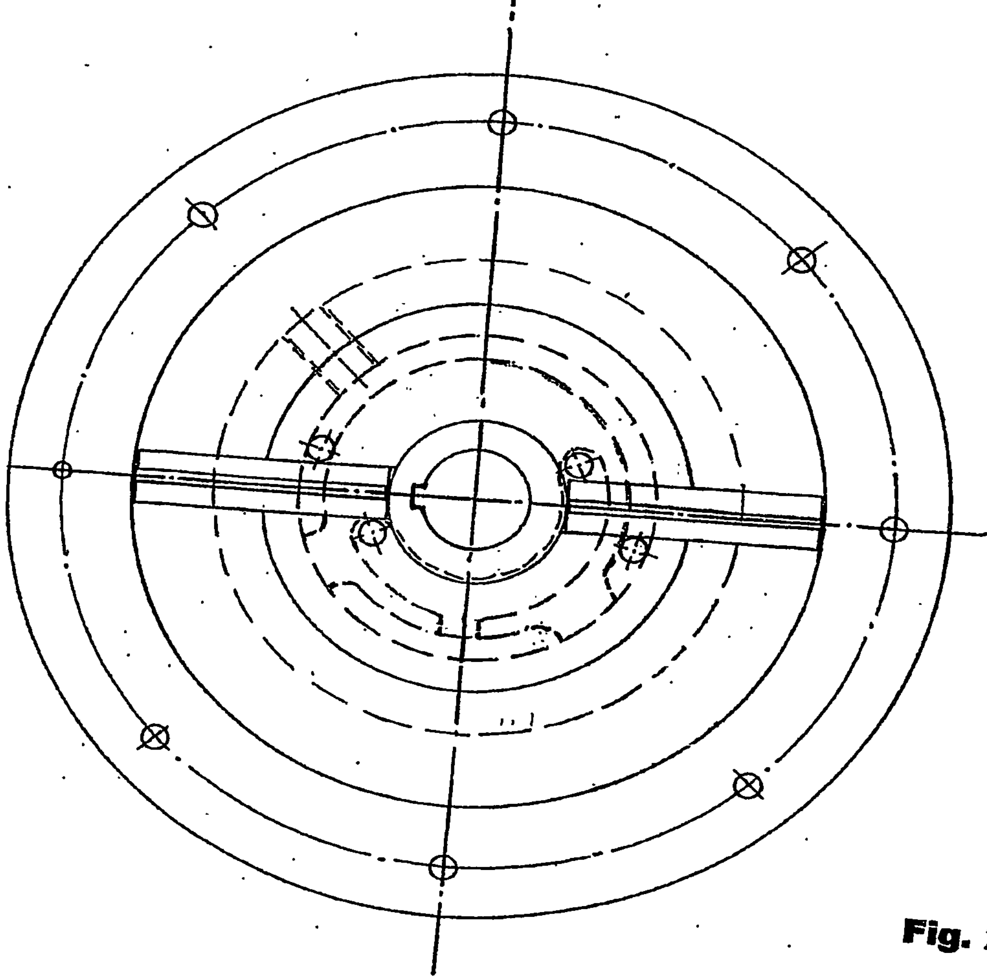
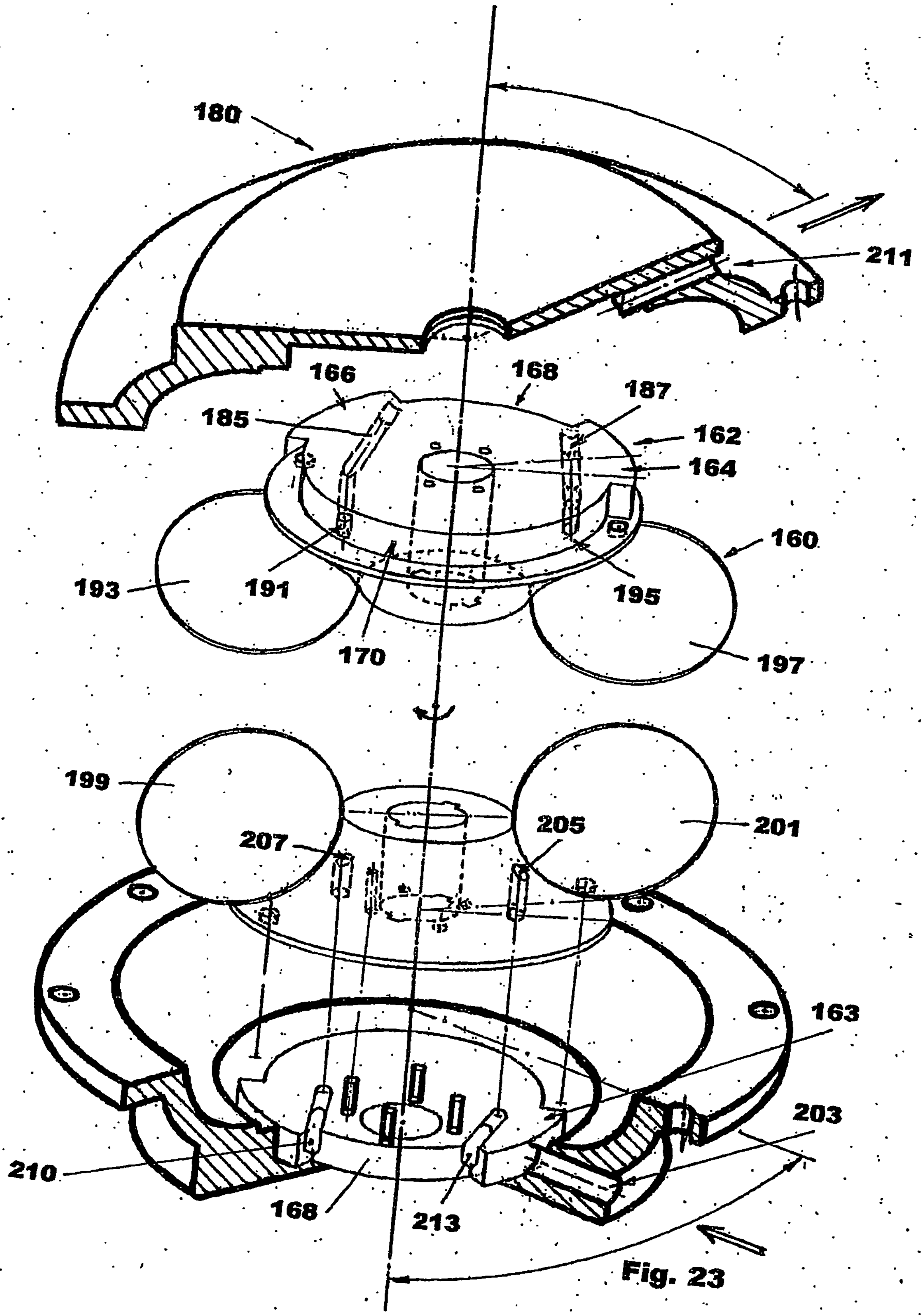


Fig. 22


180
211
166
168
187
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193
191
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170
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205
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163
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210
168
213

Fig. 23

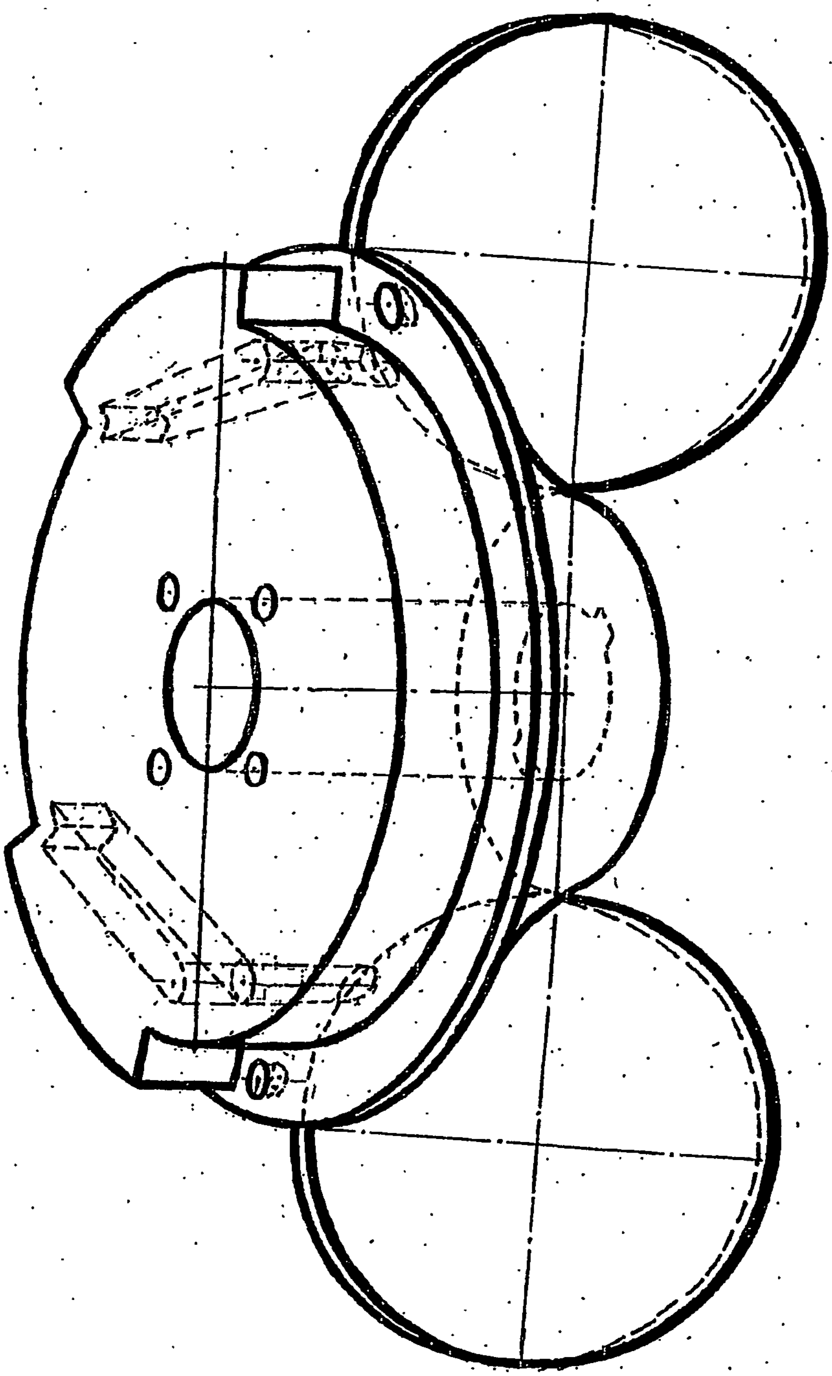


Fig. 24

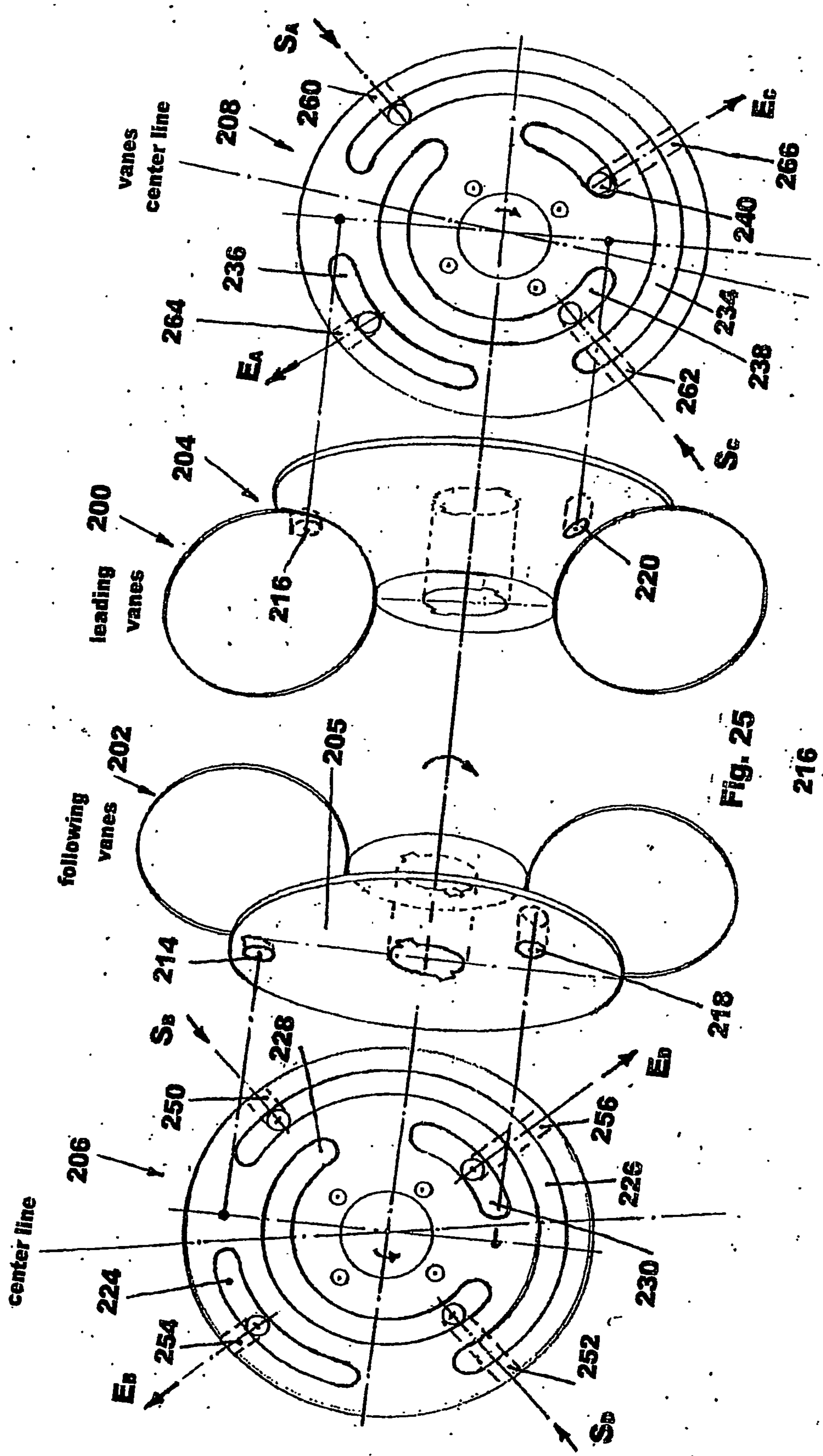
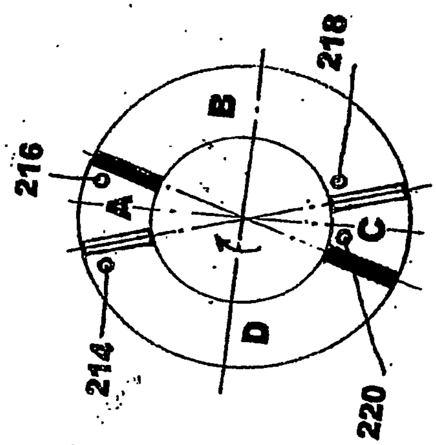

vanes center line
center line
leading vanes
following vanes
200
202
204
205
206
208
214
216
218
220
224
226
228
230
234
236
238
240
250
252
254
256
260
262
264
266
S_A
S_B
S_C
S_D
E_A
E_B
E_C
E_D

Fig. 25


A
B
C
D
214
216
218
220

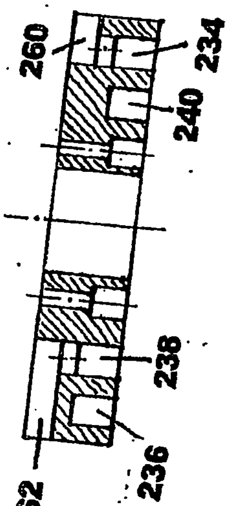

260
234
240
238
262
236

Fig. 27

...pression (mixing air and fuel) ... units and third unit ... purpose

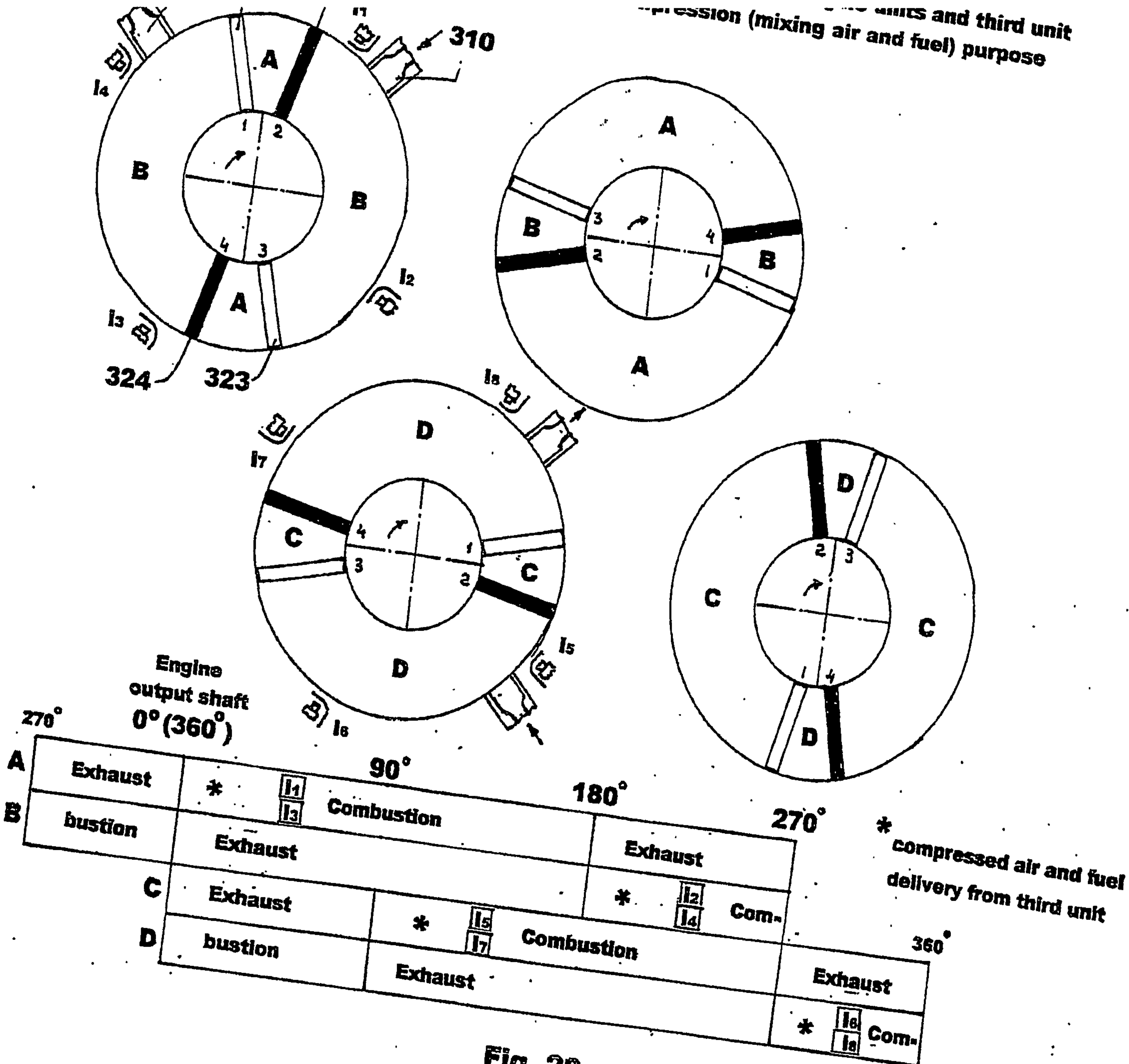
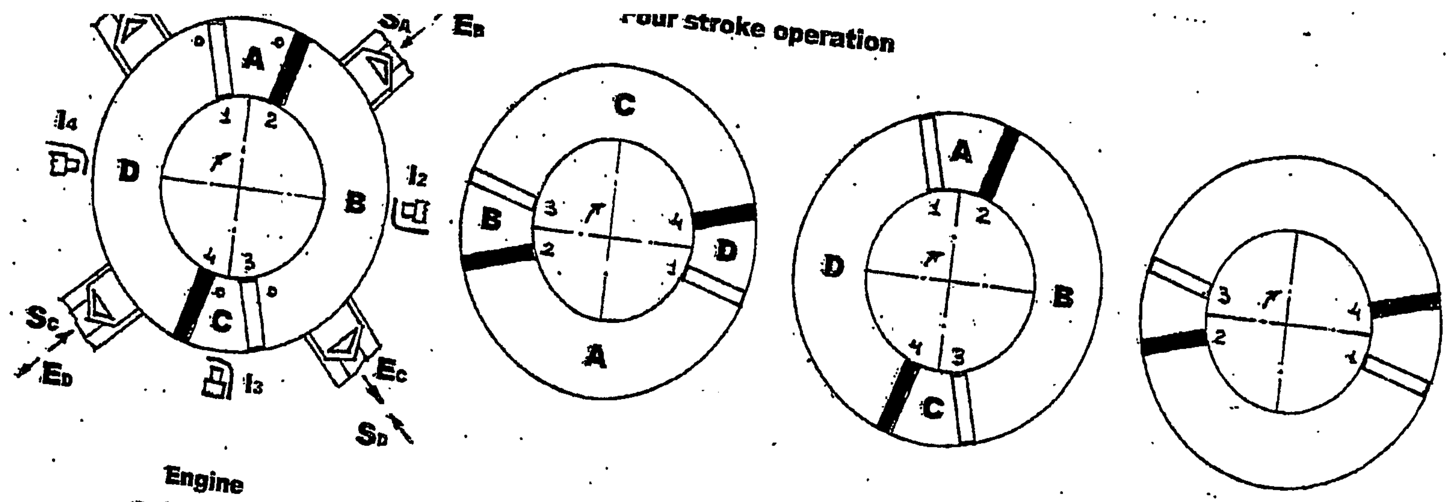


Fig. 28

Four stroke operation



Engine output shaft

0° (720°)

	630°–0°	0°–180°	180°–360°	360°–540°	540°–630°
A	E_A open	Suction, S_A open	Compression, E_A closed $\boxed{I_1}$	Combustion, S_A closed	Exhaust,
B	S_B open	Compression, E_B closed	$\boxed{I_4}$ Combustion, S_B closed	Exhaust, E_B open	Suction,
C	sion, E_C closed	$\boxed{I_3}$ Combustion, S_C closed	Exhaust, E_C open	Suction, S_C open	Compres-
D	tion, S_D closed	Exhaust, E_D open	Suction, S_D open	Compression, E_D closed $\boxed{I_2}$	Combus-

Fig. 29

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